

REFERENCE VOLTAGE SOURCE, TEMPERATURE SENSOR, TEMPERATURE  
THRESHOLD DETECTOR, CHIP AND CORRESPONDING SYSTEM

The domain of the invention is electronics and microelectronics. More precisely, the invention relates to bandgap reference voltage sources, providing a controlled voltage as a function of the temperature and  
5 with a low power supply voltage and a low standby current.

There are several applications of voltage sources controlled as a function of the temperature, and particularly:

- 10       -     reference voltage or current sources outputting a voltage or a current independent of the temperature; and
- temperature probes.

This type of bandgap reference voltage source is  
15 used particularly in portable equipment powered by batteries or systems using complex high performance electronic circuits. These applications have recently

increased particularly with the widespread use of smart cards and built-in microcontrollers.

An integrated circuit (IC) is one basic element essential for these applications, and requires a  
5 reference voltage and current source capable of supporting most analogue functions. In this type of system, it is desirable for this voltage reference to operate at a relatively low power supply voltage, for example of the order of 1.2 to 3.0 volts. It is also  
10 desirable for it to be stable and fairly well immunised against variations of the temperature, power supply and noise.

A circuit called the bandgap reference voltage source can be used to supply this required stable  
15 reference. This type of circuit is used particularly for a variety of applications such as a power supply supervisor, a Power On Reset (POR) for a device or an analogue / digital conversion. However, one disadvantage of most reference voltage sources is that they require  
20 the use of a power supply voltage higher than the reference voltage produced (for example a power supply of the order of 2.5 volts to produce a reference voltage of about 1.25 volts).

Thus in some cases, this disadvantage is overcome by  
25 using two current sources each producing a current with opposite variations depending on the temperature:

- the first source produces a first PTAT (Proportional To the Absolute Temperature) current ();

and

- the second source produces a second CPTAT (Conversely Proportional To the Absolute Temperature) current.

This type of bandgap reference voltage source based  
5 on PTAT/CPTAT currents is also described in an IEEE  
Journal of Solid State Circuits in an article published  
in May 1999 entitled "A CMOS bandgap reference circuit  
with sub-1-V operation" written by Hiromeri Bomba,  
Hitoshi Shigs, Akira Unezawa, Takeshi Miyaka, Tocu  
10 Tanazawa, Shigeru Atsumi and Koji Sakui. This reference  
voltage source is adapted to low voltage power supplies.

On the other hand, it has the disadvantage that it  
requires the use of at least three relatively high  
resistances to obtain a low operating current. Thus, the  
15 size of these resistances may be prohibitive in some  
processes, particularly processes comprising  
polycrystalline silicon resistances.

One particular objective of the various aspects of  
the invention is to overcome these disadvantages  
20 according to prior art.

More precisely, one purpose of the invention is to  
supply a bandgap voltage source outputting a controlled  
voltage as a function of the temperature and with a low  
power supply voltage and low standby current.

25 Another purpose of the invention is to provide a  
bandgap voltage source supplying a controlled voltage as  
a function of the temperature, enabling low consumption  
while limiting the silicon area related to the electrical  
resistances necessary for making the voltage source.

Yet another purpose of the invention is to enable flexible regulation of the required reference voltage as a function of the application.

Another purpose of the invention is to supply a  
5 bandgap voltage source compatible with many applications, and particularly a reference voltage source supplying a reference voltage independent of the temperature or a temperature probe based on the use of the voltage source.

These purposes and others that will become clear  
10 later are achieved according to the invention using an bandgap electrical reference voltage source comprising:

- a first electrical current source adapted to produce a first current proportional to a temperature within an operating range of the source; and
- 15 - a second electrical current source adapted to produce a second current inversely proportional to the temperature;

remarkable in that the first and the second current sources are installed in parallel, and in that the  
20 voltage source comprises means of summing the first and second currents producing a reference current in the summation means generating the reference voltage at the terminals of the summation means.

Thus, within the operating range of the voltage  
25 source, preferably between  $-40^{\circ}\text{C}$  and  $+105^{\circ}\text{C}$ , variations in the reference voltage are known as a function of the parameters of the different source elements. In some cases, the source may be made such that variations of the reference voltage within the operating range will be

negligible, or even zero. Thus, very precise reference voltage sources can be obtained, for example with a precision of the order of  $\pm 2\%$ .

According to one particular characteristic, the voltage source is remarkable in that the summation means comprise at least one first electrical resistance through which at least part of the reference current will pass.

Thus, the summation means are relatively easy to implement, while enabling good precision in a current / voltage conversion.

According to one particular characteristic, the voltage source is remarkable in that the first current source comprises:

- first current generation means adapted to produce at least one third current proportional to the temperature; and

- a first current mirror adapted to produce the said first current as a function of the third current(s).

According to one particular characteristic, the voltage source is remarkable in that the first current generation means comprise:

- at least one first operational amplifier and at least one transistor adapted to produce the third current(s);

- at least one bias resistance adapted to adjust the amplitude of the third current(s); and

- at least two bipole transistors coupled together such that the voltages between the base and the emitter of the transistors are connected through an

equation of the diode junction type dependent on the temperature.

According to one particular characteristic, the voltage source is remarkable in that the first current generation means comprise:

- an operational amplifier among the first operational amplifier(s), with first and second inputs;

- a first field effect transistor adapted to produce a fourth current;

- a second field effect transistor adapted to produce a fifth current;

- a first bias resistance adapted to adjust the amplitude of the fifth current; and

- first and second bipole transistors coupled such that the voltages between the base and the emitter of the transistors are connected through a diode junction type equation dependent on the temperature, the collectors and bases of the bipole transistors being connected to a first voltage potential;

the first, second field effect transistors cooperating with a third field effect transistor to form the first current mirror such that the first current is a function of the fourth and fifth currents;

the drain of the first field effect transistor being connected to the first bipole transistor and the first input of the operational amplifier;

the drain of the second field effect transistor being connected to the second input of the operational

amplifier and to a first terminal of the first bias resistance;

the second terminal of the first bias resistance being connected to the emitter of the second bipole transistor; and

the output from the operational amplifier being connected to each of the grids of the first, second and third field effect transistors.

According to one particular characteristic, the voltage source is remarkable in that the said second current source comprises:

- second current generation means adapted to produce at least one sixth current inversely proportional to the temperature; and
- a second current mirror adapted to produce the second current as a function of the sixth current(s).

According to one particular characteristic, the voltage source is remarkable in that the second current generation means comprise:

- at least one second operational amplifier and at least one transistor adapted to produce the sixth current(s); and
- at least one bias resistance adapted to adjust the amplitude of the sixth current(s).

According to one particularly characteristic, the voltage source is remarkable in that the second current generation means comprise:

- an operational amplifier among the second operational amplifier(s) with first and second inputs;

- a fourth field effect transistor adapted to produce a seventh current;

- a second bias resistance adapted to adjust the amplitude of the seventh current;

5        the fourth field effect transistor forming the second current mirror with a fifth field effect transistor such that the second current is a function of the seventh current;

10       the drain of the fourth field effect transistor being connected to the second input of the operational amplifier and to the first terminal of the second bias resistance;

      the second terminal of the second bias resistance being connected to the first voltage potential;

15       the first input of the operational amplifier being connected to the emitter of the first bipole transistor;

      the drain of the first field effect transistor being connected to the first input of the operational amplifier among the second operational amplifier(s); and

20       the output from the operational amplifier being connected to each of the grids of the fourth and fifth field effect transistors.

      According to one particular characteristic, the voltage source is remarkable in that it also comprises:

25       - a bias source to supply a starter current to the first and second current sources and to the summation means;



- means of starting the first and second current sources and the summation means, the summation means being powered by the starter voltage.

Thus, according to the invention, the starter  
5 current prevents an equilibrium point at a zero reference voltage.

According to one particular characteristic, the voltage source is remarkable in that the start means comprise sixth, seventh and eighth field effect  
10 transistors, the grid of each of the transistors being powered by the starter voltage and the source of each of the transistors being powered by a power supply voltage from the voltage source;

- the drain of the sixth field effect transistor  
15 being connected to the drain of the first field effect transistor;

- the drain of the seventh field effect transistor being connected to the drain of the second field effect transistor; and

20 - the drain of the eighth field effect transistor being connected to the drains of the third and fifth field effect transistors.

According to one particular characteristic, the voltage source is remarkable in that a variation of the  
25 second current as a function of the temperature compensates for a variation of the first current as a function of the temperature, such that the reference current is independent of the temperature.

Thus, the invention enables relatively simple use of a reference voltage source that does not depend on the temperature within a determined operating range.

5 According to one particular characteristic, the voltage source is remarkable in that a variation of the second current as a function of the temperature does not compensate for a variation of the first current as a function of the temperature, such that the reference current does depend on the temperature.

10 According to one particular characteristic, the voltage source is remarkable in that a variation in the reference current is proportional to a variation in the temperature.

15 Thus, the invention enables a relatively simple use of a bandgap reference voltage source for which the variation depends on the temperature according to a known and predetermined law.

20 The invention also relates to a temperature sensor and / or a temperature threshold detector comprising an bandgap electrical voltage source like that described above, remarkable in that the temperature sensor and / or the temperature threshold detector also comprise means of measuring the reference voltage.

25 According to one particular characteristic, the temperature sensor and / or the temperature threshold detector are remarkable in that the temperature sensor and / or the temperature threshold detector also comprise:

- means of generating a voltage independent of the temperature within the operating range; and

- means of comparison of the reference voltage and the voltage independent of the temperature.

5        Thus, the invention enables a relatively simple use of a reliable and precise sensor and / or temperature detector.

      The invention also relates to a chip comprising a bandgap voltage source like that described above.

10       The resistances of the voltage source according to the invention are usually relatively low and thus enable implementation in the form of a relatively economic and reliable electronic chip.

      The invention also relates to a system comprising a bandgap voltage source like that described previously, and an electronic device powered by a voltage source.

      According to one particular characteristic, the electronic device belongs to the group comprising:

- analogue / digital and / or digital / analogue  
20 converters;
- microprocessor cards;
- radio-telephones;
- battery charge regulation circuits;
- electronic devices dedicated to vehicles;
- 25 - temperature sensors;
- electrical power supply supervisors;
- digital / analogue and / or analogue / digital  
conversion devices;
- reset circuits;

- electronic devices dedicated to spacecraft;
- electronic devices dedicated to military vehicles; and
- audio or audiovisual devices.

5       The advantages of the temperature sensor, the temperature threshold detector, the chip and the system are the same as the advantages of the bandgap voltage source and are not described in more detail.

10       Other characteristics and advantages of the invention will become clear after reading the following description of a preferred embodiment, given as a simple illustrative and non-limitative example and the attached drawings, among which:

15       - Figure 1 shows a block diagram of one particular embodiment of the bandgap voltage source according to the invention;

      - Figure 2 illustrates the voltage source in figure 1 without the bias and starter circuit;

20       - Figure 3 describes a bias circuit like that illustrated with respect to figure 1;

      - figure 4 illustrates a voltage source according to figure 1, designed to operate with the bias circuit according to figure 3; and

25       - figure 5 illustrates a block diagram of a particular embodiment of the sensor and / or temperature threshold detector comprising a voltage source conform with the invention.

      The general principle of the invention is based on a bandgap reference voltage source comprising:

- a PTAT current source proportional to the absolute temperature;

- a CPTAT current source conversely proportional to the absolute temperature ;

5        - summation means to add the PTAT current and the CPTAT current to produce a reference voltage at its terminals (for example, these summation means may include a summation resistance).

10       The PTAT and CPTAT current sources are installed in parallel so that a power supply voltage similar to the reference voltage produced can be used.

      The reference voltage produced by the source can be adjusted by varying the value of a summation resistance.

15       When the variations of the CPTAT current as a function of the temperature precisely compensate for the variations of the PTAT current, the sum of the PTAT and CPTAT currents is independent of the temperature. In this case, the reference voltage at the terminals of the summation means through which the current passes obtained  
20       by adding the PTAT and CPTAT currents is constant, and is also independent of the temperature. Therefore, the reference voltage source can be used as a source of a voltage that does not vary with temperature.

25       On the other hand, when the construction is such that variations of the CPTAT current as a function of the temperature do not precisely compensate for the variations in the PTAT current, the reference current passing through the summation means also varies as a function of the temperature. In this case, the reference

voltage source can be used to measure a temperature of the ambient medium. Preferably, the current sources are adapted so that current variations remain proportional to temperature variations, the sum of the PTAT and CPTAT  
5 currents then varying in proportion to the temperature variation. In this case, the reference current at the terminals of the summation means through which the current passes obtained by adding the CPTAT and PTAT currents also varies proportionally to the temperature  
10 variation. If the summation means are composed of one or several resistances, the reference voltage also varies proportionally to the temperature, which enables a relatively simple use of a temperature probe.

Figure 1 shows a general block diagram of a voltage  
15 source device according to one particular embodiment of the invention.

The device comprises:

- a bandgap voltage source 104 supplying a reference voltage VREF;
- 20 and
- a bias and starter module 100.

The bandgap voltage source 104 and the bias module 100 are powered by a voltage VCC 110 and are connected to a ground 111.

25 The bias module 100 supplies a bias and starter voltage vbias through a link 112.

The bandgap voltage source 104 comprises:

- a PTAT current source proportional to the absolute temperature 101;

- a CPTAT current source conversely proportional to the absolute temperature 102; and
- an electrical summation resistance R3.

The current sources 101 and 102 are connected to the  
5 potential VCC through the link 110, to the ground 111 and  
to the bias and starter voltage vbias 112.

The PTAT current source 101 outputs a current I4 on  
an output 120.

The CPTAT current source 102 outputs a current I5 on  
10 an output 130.

The outputs 120 and 130 are connected to a terminal  
140 of the resistance R3, the other terminal 141 of the  
resistance R3 being connected to the ground 111.  
Therefore the PTAT current I4 and the CPTAT current I5  
15 are added in the resistance R3.

The voltage VREF is taken between the terminals 140  
and 141 of the resistance R3. Thus, as indicated above,  
if the variation of the PTAT current as a function of the  
temperature is exactly compensated by the variation of  
20 the CPTAT current, the sum of the two currents passing  
through the resistance R3 is constant and therefore the  
voltage VREF supplied at the terminals of the resistance  
R3 is constant.

On the other hand, if the sum of the PTAT and CPTAT  
25 currents varies as a function of the temperature, the  
measurement of the VREF voltage at terminals 140 and 141  
of the resistance R3 provides a means of determining the  
temperature (operation in temperature probe).

Figure 2 illustrates the bandgap reference voltage source 104 according to one embodiment of the invention. The circuits specific to bias and starting are not shown, in order to clearly show operation of the source 104. The source 104 can operate without a starter current but in this case there is a risk that some components of the source 104 will remain energised at zero voltage. Therefore, it is preferable to impose a starter current in order to overcome this disadvantage.

As mentioned above, the reference voltage source 104 comprises:

- a PTAT current source proportional to the absolute temperature 101;
- a CPTAT current source conversely proportional to the absolute temperature 102; and
- an electrical summation resistance R3.

The PTAT current source 101 comprises:

- a first current mirror 200 comprising three MOS field effect transistors (FET) M1, M2 and M3;
- a resistance R1;
- a pair of PNP bipole semi-conducting bipole transistors Q1 and Q2 with sizes SQ1 and SQ2 respectively; and
- a first operational amplifier A1.

The load resistance R3 is connected to the output from the two current mirrors 200 and 201 through terminal 140.

The MOS transistors M1, M2 and M3 are coupled so as to form the first current mirror 200:



- the sources of transistors M1, M2 and M3 are connected to potential VCC (link 110);
- the drain of the transistor M1 is connected to a node N2 and outputs a current I1;
- 5       - the drain of transistor M2 is connected to a node N1 and outputs a current I2;
- the drain of transistor M3 is connected to terminal 140 of resistance R3 and outputs a current I4; and
- 10       - the grids of transistors M1, M2 and M3 are connected to the output from the operational amplifier A1.

In this case, the operational amplifiers refer to devices that make a direct comparison between two voltage levels or two voltage signals and supply an amplified output voltage signal response based on a comparison of the voltage signals.

According to techniques known to those skilled in the art, the current passing through a MOS FET transistor is proportional to the width of the grid of the device.

20       The ratio between the current I1 and the current I2 is thus determined by the ratio of the dimensions of the grids of the MOS transistors M1 and M2; similarly, the ratio between the current I1 and the current I3 is

25       determined by the ratio of the dimensions of the grids of the MOS transistors M1 and M3. The widths of the grids of the MOS transistors M1, M2 and M3 are the same. Thus, for example:

- the current  $I_1$ , for example equal to approximately  $1\ \mu\text{A}$  passes through node N2;

- the current  $I_2$ , for example equal to approximately  $1\ \mu\text{A}$  passes through node N1;

5       - the current  $I_4$ , for example equal to approximately  $1\ \mu\text{A}$  passes through the MOS transistor M3;

The grids of MOS transistors M1, M2 and M3 are electrically coupled to the voltage comparison at node N6, generated by amplifier A1. Since the voltage at node  
10 N6 is supplied by amplifier A1, the grid-source voltages of MOS transistors M1, M2 and M3 are approximately equal and the MOS transistors M1, M2 and M3 operate at or close to a saturation region during operation of the voltage source 104.

15       The negative input to amplifier A1 is connected to node N2 while the positive input of amplifier A1 is connected to node N1. The output from the amplifier A1 is connected to node N6. The amplifier A1 is powered through the vbias voltage. Thus, the amplifier A1 compares the  
20 voltage between nodes N2 and N1.

By activating the MOS FET transistor M2 to output a current  $I_2$ , the amplifier A1 causes the creation of a voltage  $V_{R1}$  at the terminals of the resistance R1. Furthermore, the consequence of reinjecting the voltage  
25  $V_{N2}$  supplied to amplifier A1 is that the electrical voltages at nodes N1 and N2 are approximately equal.

Two PNP bipole transistors Q1 and Q2 are coupled at currents  $I_1$  and  $I_2$  respectively. The emitter of transistor Q1 is directly connected to node N2. The

emitter of transistor Q2 is connected to node N1 through a resistance R1. The collector and the base of transistors Q1 and Q2 are connected to the ground 111.

The relation of transistors Q1 and Q2 approximately follows a diode junction equation. The base-emitter voltage on each transistor in the pair of PNP transistors Q1 and Q2 is provided by the equation:

$$V_{BE\_Q1} = V_{BE\_Q2} + kT/q \ln(J1/H2) \quad (1)$$

where:

- 10        -     J1 is the current density passing through transistor Q1;
- J2 is the current density passing through transistor Q2;
- $kT/q$  is the thermal voltage, where  $k$  is Boltzman's constant,  $T$  is the absolute temperature and  $q$  is the charge of the electron ( $1.6 \times 10^{-19}$  coulombs);
- 15        -      $V_{BE\_Q1}$  is the base-emitter voltage of transistor Q1;
- and  $V_{BE\_Q2}$  is the base-emitter voltage of transistor Q2.
- 20

The current densities J1 and J2 may be adjusted by modifying the ratio of the surface areas of the emitters of transistors Q1 and Q2. In the described embodiment, the currents I1 and I2 are identical and the surface area of the emitter of transistor Q2 is equal to at least eight times the surface area of the emitter of transistor Q1.

Furthermore, since the voltages on nodes N1 and N2 are approximately equal, the base-emitter voltage at the

terminals of the PNP transistor Q1 is approximately equal to the base-emitter voltage at the terminals of the PNP transistor Q2, to which the voltage at the terminals of the resistance R1 is added. A voltage difference between  
 5 the base-emitter voltages VBE\_Q1 and VBE\_Q2 of the PNP transistors Q1 and Q2 respectively, appears in the form of a voltage V\_R1 at the terminals of the load resistance R1 according to the following relation:

$$10 \quad V_{R1} = V_{BE\_Q1} - V_{BE\_Q2} \quad (2)$$

Equations (1) and (2) can be combined to give:

$$15 \quad V_{R1} = kT/q \times \ln(J1/J2) \quad (3)$$

Since the width and the length of the MOS devices M1, M2 and M3 in the current mirror 104 are identical, the currents in transistors M1, M2 and M3 are given by:

$$20 \quad I_{PTAT} = (kT/qR1) \times \ln(J1/J2) \quad (4)$$

For example, if:

- the value of the resistance R1 is fixed at 56 kΩ;
  - 25 - the ratio of the sizes of the emitters of PNP devices Q1/Q2 is equal to 8; and
  - the ratio of the sizes of the MOS devices M1/M2 is equal to 1;
- then,

- according to relation (3), voltage  $V_{R1}$  is equal to:

$$V_{R1} = (kT/q) \cdot \ln(8) = (1.38 \times 10^{-23} \cdot 300 / 1.6 \times 10^{-19}) \ln 8 = 54 \text{ mV}$$

5 at a temperature  $T = 300\text{K}$ ; and

- according to relation (4), the  $I_{PTAT}$  current is equal to  $V_{R1}/R1 = 1 \mu\text{A}$ .

The CPTAT current source 102 comprises:

- a second current mirror 201 comprising two MOS  
10 field effect transistors M4 and M5;

- a second operational amplifier A2 with a current mirror controlling the output 130; and

- a load resistance R2 connected to a reinjection input.

15 The CPTAT current source 102 is used:

- firstly as a voltage follower to output a voltage VNG equal to the voltage at the terminals of the PNP device Q1;

- then as a current source with a "negative  
20 temperature coefficient" to supply a current through the second current mirror 201 equal to the current in the resistance R2.

The MOS transistors M4 and M5 are coupled so as to form the second current mirror 201, the source and grid  
25 of the transistor M5 being connected to the source and grid of the transistor M4 respectively:

- the sources of transistors M4 and M5 are connected to the potential VCC (link 110);

- the drain of transistor M5 is connected to a node N3 and outputs a current I3;

- the drain of transistor M4 is connected to the terminal 140 of the resistance R3 and outputs a current I5; and

- the grids of transistors M4 and M5 are connected to the output from the operational amplifier A2.

The ratio between the current I3 and the current I5 is determined by the ratio of the dimensions of the grids of MOS transistors M4 and M5. The widths of the grids of MOS transistors M4 and M5 are exactly the same such that the current I5 in transistor M4 is identical to the current I3 in transistor M5.

Thus, for example:

- current I3, for example equal to approximately 1  $\mu$ A, passes through node N3; and

- current I5, for example equal to approximately 1  $\mu$ A, passes through the MOS transistor M3.

The grids of MOS transistors M4 and M5 are electrically coupled to the voltage comparison at node N4 output by amplifier A2. The voltage at node N4 is supplied by amplifier A2, therefore the grid-source voltages of MOS transistors M4 and M5 are approximately equal and the MOS transistors M4 and M5 operate at or close to a saturation region during operation of the voltage source 104.

The positive input to amplifier A2 is connected to node N3, while the negative input of amplifier A2 is

connected to node N2. The output from amplifier A2 is connected to node N4. The amplifier A2 is powered through the voltage vbias.

5 The resistance R2 connects the ground 111 to node N3 corresponding to the output from a voltage follower.

The voltage follower is connected using the amplifier A2 and the MOS transistor M5.

10 The amplifier A2 and the first part of the second current mirror 105 are connected as follows, to form the voltage follower:

- the negative input to amplifier A2 is connected to transistor Q1 through node N2;
- the positive input to amplifier A2 is connected to the drain of transistor M5 and to the load resistance 15 R2 through the node N3;
- the output from amplifier A2 is connected to the grid of transistor M5 through a node N4; and
- the source of the transistor M5 is connected to the power supply VCC through the link 110.

20 Since the width and length of M5 and M4 are identical, the current in the resistance R2 and the mirror 201 is then supplied by the equation:

$$I_{CPTAT} = VBE_{Q1}/R2 \quad (5)$$

25

where  $VBE_{Q1}$  represents the base-emitter voltage of transistor Q1.

For example,  $R_2$  is preferably between 100 and 500  $k\Omega$ , and for example may be fixed at 420  $k\Omega$ , and thus  $I_{CPTAT}$  is equal to 1.9  $\mu A$ .

The resistance  $R_3$  is used to add the  $I_{PTAT}$  and  $I_{CPTAT}$  currents. Relations (4) and (5) can be combined, so that the voltage at the terminals of resistance  $R_3$  is given by the equation:

$$V_{REF} = R_3 \times (V_{BE\_Q1}/R_2 + (kT/qR_1) \times \ln(J_1/J_2)) \quad (6)$$

10

Thus  $V_{REF}$  is the sum of two terms:

- a voltage proportional to  $V_{BE\_Q1}$  and which therefore varies conversely to temperature variations ( $V_{BE\_Q1}$  goes down when the temperature  $T$  goes up); and
- 15 - a voltage that varies proportionally to the temperature.

For illustration purposes, according to the embodiment described, the values of parameters related to the components used are as follows:

- 20 - the values of resistances  $R_1$ ,  $R_2$  and  $R_3$  are preferably between 100 and 500  $k\Omega$ , and for example their values may be 56  $k\Omega$ , 420  $k\Omega$  and 332  $k\Omega$  respectively;
- the ratio of the surface area of the emitter of  $Q_2$  to the surface area of the emitter of  $Q_1$  is equal to
- 25 8; and
- the width  $W$  of the grid of transistors  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$  and  $M_5$  is equal to 120  $\mu m$  and the grid length  $L$  is equal to 40  $\mu m$ .



Thus, at a temperature  $T$  equal to 300 K, the voltage  $V_{BE\_Q1}$  is close to 0.6V (half the prohibited band of silicon for bipole transistors) and according to relation (6):

5

$$V_{REF} = 332 \times 10^3 (V_{BE\_Q1} / 420 \times 10^3 + 54 \times 10^{-3} / 56 \times 10^3) \# 332 (0.6 / 420 + 10^{-3})$$

namely  $V_{REF} = 0.8V$ .

Figure 3 describes a bias and starter circuit 100 like that described with reference to figure 1. The bias and starter circuit 100 is a current source which has the advantage of supplying a stable current when the power supply voltage  $V_{CC}$  varies. Thus, the current in each of the amplifiers A1 and A2 is also stable, which enables stable performances (particularly in terms of offset) and a good precision of the supplied reference voltage.

- The bias and starter circuit 100 comprises:
- transistors MPB0, MPB1, MPB2, I31, I32, MNST1, MNB1 and MNB2;
  - an electrical resistance RPOL; and
  - a capacitor CST.

The source of each of the transistors MPB0, MPB1, MPB2 and I32 is connected to the power supply voltage  $V_{CC}$ ;

MNB1 and MNB2 are composed of 4 and 16 identical transistors, respectively, installed in parallel. Only one transistor MNB1 and one transistor MNB2 have been shown facing figure 3, in order to simplify the view.

The grid of each transistor MPB0, MPB1 and MPB2, and the drain of transistor MNB2 are connected to bias circuit 100.

5 The drain of transistor MPB1 is connected to the drain of each of transistors MNST1 and MNB1 and to the grid of each of transistors MNB1 and MNB2. The drain of transistor MPB1 outputs a current iBIAS;

10 The drain of transistor MPB0 is connected to one of the terminals of the capacitor CST (the other terminal of this element being connected to the ground 11) and to the grid of each of the transistors I31 and I32.

The drain of transistor I32 is connected to the grid of transistor MNST1 and to the drain of transistor I31.

15 The source of each transistor MNST1 and MNB1 is connected to the ground 111.

The source of each transistor MNB2 is connected to one of the terminals of the resistance RPOL, and the other terminal of this resistance is connected to the ground 111.

20 The currents output by transistor MPB1 (denoted I\_MPB1) and by transistors MNB1 (denoted I\_MNB1) are given by the relation:

$$iBIAS = I\_MPB1 = I\_MNB1 = \frac{(1-n/m)^2}{(n \times uC0 / 2 \times W/L\_NB1 \times RPOL^2)}$$

25 where

$$- \quad m = (W/L\_NB2) / (W/L\_NB1)$$

$$- \quad n = (W/L\_PB2) / (W/L\_PB1)$$

and in which:

- parameters  $L_{NB1}$  and  $L_{NB2}$  represent the grid lengths (in other words the distance between the drain and the source) of the transistors  $MNB1$  and  $MNB2$  respectively; and

5        - the parameter  $W$  is their length.

This type of current source requires a starter circuit. The starter circuit is made by transistor  $MNST1$ .  $MNST1$  is deactivated by transistor  $I31$  after capacitor  $CST$  has been charged at voltage  $VCC$  by transistor  $MPB0$ .

10        As an illustrative example, the values of parameters of components of the bias circuit 100 according to the described embodiment may be as follows:

- the capacitance of the capacitor  $CST$  is greater than or equal to 1 pF to avoid parasite capacitances, and  
15        for example is chosen to be equal to 1 pF;

- the integrated poly-silicon resistance  $RPOL$  is equal to 120 k $\Omega$ ;

- the width of the grid of transistors  $MPB0$ ,  $MPB1$  and  $MPB2$  is equal to 10  $\mu m$  and their length is equal to  
20        1.26  $\mu m$ ;

- the width of the grid of transistors  $I31$  and  $I32$  is equal to 2.5  $\mu m$  and 5  $\mu m$  respectively, and their length is equal to 0.35  $\mu m$ ;

- the width of the grid of transistor  $MNST1$  is  
25        equal to 4.9  $\mu m$  and its length is equal to 0.35  $\mu m$ ;

- the width and length of the grid of each transistor  $MNB1$  and  $MNB2$  are equal to 26  $\mu m$  and 1.2  $\mu m$  respectively.

Figure 4 illustrates a voltage source 104 according to figure 1 designed to operate with the bias circuit 100 described with reference to figure 3.

The voltage source 104 in figure 4 comprises:

- 5        - elements of the voltage source 104 illustrated with regard to figure 2; and
- the FET transistors M6, M7 and M8.

Elements common to the voltage sources illustrated with reference to figures 2 and 4 are the same, and  
10 consequently they will not be described further.

Transistors M6, M7 and M8 enable satisfactory start-up of the voltage source 104. For example, the width of the grid of transistors M6, M7 and M8 is equal to 10  $\mu\text{m}$  and their length is equal to 1.26  $\mu\text{m}$ , these dimensions  
15 being identical to the dimensions of transistors MPB0, MPB1 and MPB2.

The source of each of the transistors M6, M7 and M8 is connected to the power supply VCC.

The grid of each of the transistors M6, M7 and M8 is  
20 connected to the bias voltage vbias.

Therefore the transistors M6, M7 and M8 are installed as a current mirror.

The drain of transistor M7 is connected to node N2 and outputs a current ISTART1, and the drain of  
25 transistor M8 is connected to node N1 and outputs a current ISTART2.

The drain of transistor M6 is connected to node 140 and outputs a current ISTART3 similar to ISTART2 and ISTART1.

The amplifier A1 of the PTAT source acts on node N6 so that the potentials at points N1 and N2 respectively are identical. In theory, there are two operating points at which the potentials at points N1 and N2 are identical:

- an unwanted point with zero current; and
- a suitable point with a non zero current.

The starter current 100 is a means of providing a non zero current at points N1 and N2 and therefore avoiding the operating point at zero current.

Furthermore, the sum of the three currents I4, I5 and ISTART3 passes the resistance R3.

Figure 5 shows a diagram of the temperature sensor and / or temperature threshold detector comprising a voltage source adapted to the temperature measurement.

The sensor and / or detector comprise elements similar to the elements in the voltage source illustrated with reference to figure 1; therefore these elements have the same references and will not be described further.

In particular, it comprises:

- a bias circuit 100;
- a voltage source 500; and
- a measurement and / or detection module 501.

The bias circuit 100 is adapted to output a bias voltage vbias at the voltage source 500.

The voltage source 504 is adapted to output two voltages:

- a reference voltage VREF independent of the temperature; and

- a voltage VTEMP to determine an ambient temperature.

The voltage source 504 comprises:

- a PTAT current source proportional to the  
5 absolute temperature 501;

- a CPTAT current source conversely proportional  
to the absolute temperature 502;

- two electrical summation resistances R3 and R4;  
and

10 - a current source 550.

The PTAT current source 501 and the CPTAT current  
source 502 form part of the sensor and / or detector that  
is immersed in the medium for which the temperature is to  
be measured and / or to detect a value exceeding a  
15 predetermined threshold. According to the embodiment  
described, the bias circuit 100, the module 501,  
resistances R3 and R4 and the source 550 do not form part  
of the sensor itself and are separate from it. According  
to one variant, the sensor and / or detector are made in  
20 a single block and all elements in the bias circuit 100,  
the source 500 and the module 501 belong to the sensor  
that is immersed in the medium for which the temperature  
is to be measured and / or to detect a temperature value  
exceeding a predetermined threshold.

25 The current sources 501 and 502 are connected to the  
potential VCC through the link 110, to the ground 111 and  
to the bias and starter voltage vbias 112.

The PTAT current source 501 provides:

- a current I4 on an output 120; and

- a current  $I_6$  on an output 520.

The PTAT current source 501 is similar to the source 101 previously illustrated with reference to figures 2 and 4, except for the current mirror 200 that also  
5 comprises a transistor M33 for which the source and the grid are connected in parallel to the source and grid respectively of transistor M3.

The surface area of the grid of transistor M33 is not the same as the surface area of the grid of  
10 transistor M3. Thus, the currents  $I_4$  and  $I_6$  output by transistors M3 and M33 respectively are different. If the grid of M33 is larger than the grid of M3, the current  $I_6$  will vary with a positive temperature coefficient.

The CPTAT current source outputs:

- 15 - a current  $I_5$  on an output 130; and
- a current  $I_7$  on an output 520.

The CPTAT current source 502 is similar to the source 102 previously illustrated with reference to figures 2 and 4, except for the current mirror 201 that  
20 also comprises a transistor M44 for which the source and the grid are connected in parallel to the source and the grid respectively of transistor M4.

Transistors M4 and M44 have identical grid widths and lengths. Thus, the current  $I_7$  output by transistor  
25 M44 is identical to the current  $I_5$  output by transistor M4.

The outputs 120 and 130 and the output from transistor M6 are connected to a terminal 140 of the resistance R3, the other terminal 141 of the resistance

R3 being connected to the ground 111. Therefore, the three currents (PTAT I4, CPTAT I5 and ISTART3) are added in resistance R4.

5 The voltage VREF is taken between terminals 140 and 141 of the resistance R3. Thus, the variation of the PTAT current as a function of the temperature is exactly compensated by the variation of the CPTAT current, and in this case the sum of the three currents passing through the resistance R3 is constant and therefore the voltage  
10 VREF output at the terminals of the resistance R3 is constant.

The voltage VTEMP is taken between terminals 540 and 141 of the resistance R4. The sum of the PTAT and CPTAT currents varies as a function of the temperature, therefore a measurement of the voltage VTEMP at the  
15 terminals 540 and 141 of the resistance R4 provides a means of determining the temperature.

An iOffset current source 550 between terminals 540 and 141 is used to adjust the offset of the temperature probe through the voltage VTEMP. Thus, the sensor and /  
20 or detector can be calibrated as a function of a reference temperature (for example a zero voltage difference can be chosen between VREF and VTEMP at a temperature T equal to 300K).

25 The measurement and/or detection module 501 comprises two inputs connected to the following terminals, respectively:

- 140 (at potential VREF independent of the temperature); and



- 540 (at potential VTEMP depending on the temperature).

Thus, for operation as a temperature probe, the measurement module 501 comprises an analogue / digital  
5 converter, for example with a precision of 10 bits, and outputs a value of the voltage difference (VTEMP-VREF) to a digital output on 10 bits, and this value can be converted directly into a temperature value.

Similarly, for operation in temperature threshold  
10 detection, the measurement module 501 includes a comparator between voltages VTEMP and VREF and outputs a value equal to one if the measured temperature is greater than a predetermined temperature threshold (value of the temperature when the two voltages VTEMP and VREF are  
15 equal), or otherwise zero, on a single-bit digital output.

Obviously, the invention is not limited to the example embodiments mentioned above.

In particular, an expert in the subject will make a  
20 number of variants to the definition of the bias circuit to supply a constant starter and bias voltage.

Furthermore, there are many variants for PTAT and CPTAT current sources. For example, the bipole transistors Q1 and Q2 could be replaced by MOS  
25 transistors.

Note that the voltage source is not limited to supplying the reference voltage VREF independent of the temperature, but it may provide a reference voltage VREF for which the variation is known as a function of the

temperature and which can be used for many applications, for example for temperature probes, and for battery charge devices (the charge voltage also varying with the temperature).

5        Temperature sensors and temperature detectors are not limited by the embodiment of the invention illustrated with reference to figure 5, but include all variants capable of supplying a voltage dependent on the temperature according to a known law. In particular, the  
10    invention concerns variants of the device illustrated with reference to figure 5 using at least two combined voltage sources (case of the embodiment in figure 5) or adjacent sources (in other words separate or independent) in which one voltage source independent of the  
15    temperature within the operating range of the device and at least one voltage source outputting at least one voltage that is dependent on the temperature. It also applies to variants for supplying at least one voltage dependent on the temperature, for example using  
20    components for controlling the voltage as a function of the temperature (for example transistors with appropriate surface areas or appropriate resistances).